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NAVAL POSTGRADUATE SCHOOL

Monterey, California

A MODEL OF THE CIC OPERATION OF ASW SHIPS

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ABSTRACT:

This paper is devoted to a detailed analysis of the information flow in the CIC on non-NTDS equipped destroyer types. Our analysis is accomplished via a model of the CIC operation which is keyed to the threat environment. The model has two fundamental components. One is the physical communications framework; the other is a message priority structure, which is determined by the threat. Recommendations for action to improve CIC performance, which are based on the analysis, are included.

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1. Introduction and history. The project order provided funds to conduct an analysis of the information flow within CIC during ASW operations, to develop a mathematical model of the time-dependent priority states of the system keyed to the threat environment, and to investigate procedures for automating priority traffic flow suitable for testing in real time in the CIC model. The investigation was conducted at the Naval Postgraduate School, originally with Professor C. E. Menneken, designated Principal Investigator, and Professors T. Jayachandran and C. O. Wilde, the other investigators.

The project was supported by ONR at a total cost of approximately one man-year, with the work distributed over a two-year period of time. During the first year considerable effort was expended in obtaining background, as part of the self-education phase, on CIC doctrine, configurations, and operations. Information was gathered from a variety of sources: manuals on strategy, tactics and operations; interviews with CIC-qualified naval officers, interviews and discussions with NPS faculty members for detailed information on such items as adaptive control systems and technical aspects of the NTDS computer; a visit to the ASW training center in San Diego to attend ROPEVAL 4-70, a mock-up of subsequent at-sea exercise; and visits aboard ships to observe actual CIC's.

In the summer of 1971 the project moved into the constructive phase, and the transition was marked by two changes in personnel. First, Professor Wilde assumed responsibility for leadership of the project and was formally designated Principal Investigator; this move was initiated and effected by Professor Menneken, who remained active and provided guidance throughout the project. The second change was the addition of Professor D. E. Harrison, Jr., to the project staff in order to bring its mathematical and computer modeling capability to the level necessary to accomplish the project task.

It was recognized early that the civilian investigators alone would be unable to provide the realism required in order to define a model which could ultimately serve a useful purpose. We needed continuous input from naval officers who were operationally experienced in the ASW/CIC environment and who possessed the academic sophistication necessary in order to establish a meaningful dialogue with the investigators. The Naval Postgraduate School proved to be an ideal location for the project in the sense that we have available a supply of officers with the combination of sea experience and advanced education required to meet the above criteria. We interviewed a large number of qualified officers and finally selected a panel of three. These officers, who faithfully participated in the formal weekly meetings with the civilian investigators over an extended period and who spent much spare time thinking and preparing written reports between meetings, are LCDR H. M. Effron, LT R. D. Horner and LT J. N. Swan.

LCDR Effron's contribution turned out to be of such magnitude as to warrant his inclusion as a co-author; and we gratefully acknowledge the dedicated effort and the vital contribution made by LT Horner and LT Swan.

We briefly mention here, as a sidelight, some "spin-off" from this project which provides direct benefits to the Navy but which is not included in the central results. First, we feel that the officers who participated in the project advanced significantly in their ability to perceive salient and essential features in naval systems and environments, to analyze these observations rationally, and to formulate their ideas, understandings and feelings in a clear, logical and usable manner. A second peripheral result is that the investigators themselves explored and developed techniques for capitalizing on the combination of operational experience and advanced education; this should enhance significantly their ability to attack and solve Navy-related problems in the future. A third benefit stems from the fact that one of the investigators is a member of the group tasked with the architecture of a proposed operational ASW curriculum at NPS; we expect that his experience gained from this project will have a positive effect on the quality of the new program. Finally, we note that our group made contacts with a number of individuals and groups working on ASW problems in various agencies, primarily at NELC and NPS, for mutually productive interchanges.

We conclude this section with a brief description of the remaining contents of this report. In section 2 we present some of the assumptions and considerations upon which our work is based. In section 3 we describe the mathematical model itself; this description contains our principal results. Section 4 is devoted to recommendations based upon our findings, suggestions for possible further development and applications of the model, and a discussion of related problems we feel potentially worthy of investigation.

2. Basic assumptions. The CIC collects, processes (including an all-important evaluation), and disseminates information used by commanders making tactical decisions, by stations which deliver weapons, and by support units such as assist ships, fixed-wing aircraft, and helicopters. In non-NTDS equipped destroyer types (DE, DD, DDG, and DLG), transmission of information, i.e. general CIC communication with sensors, the bridge, and external stations, is effected through a complex array of voice circuits, phone lines, talkers, messengers, and more exotic means of communication.

It was a general consensus on the part of our CIC-experienced officers that although the ASW/CIC has some degree of effectiveness in the simplest tactical situation, i.e. one-on-one, destroyer vs. submarine, there do exist serious problems even in this setting. (We shall not elaborate on these problems because it was also agreed that the one-on-one situation is unrealistic, that is it should not be expected to occur in actual practice.) There was strong agreement that even a small increase in complexity of the tactical problem causes a sharp deterioration in both the reliability and the effectiveness of the system. Our panel agreed that even in a situation where a contact is prosecuted with the help of one assist ship and one support aircraft, several serious problems arise. There are often delays in transmission of information, crucial information is sometimes lost, there is an overcrowding of personnel at certain critical locations, the noise level in "Combat" is at times so high as to interfere with communications, and some equipment is unreliable, all of which problems often culminate in misleading or simply inaccurate interpretations.

There are other major problem areas associated with the "manually" operated CIC, which fall under the general headings of human factors and group dynamics. One problem is that the CIC operation, and even to some degree its configuration, often depend too heavily on various characteristics of key personnel in the system, especially the evaluator. In addition, the efficiency and the reliability of the system depend to an inordinate degree on crew training and experience. These excessive dependencies seem to have clearly undesirable aspects; for example, the quality of message transmission via several vocal means, especially sound-powered phones, is easily affected by the ability of one man to understand another's accent. Another example is that the evaluator's actions, including his physical movements, may very well be dictated by the degree of his confidence in the CIC team, rather than by basic performance optimization criteria for the system.

The problems described above, and others which we have omitted, are apparently sharply diminished in the newer highly automated systems, for example the NTDS used in AAW. Although NTDS has its own set of problems, much of the concept seems fundamentally sound, and current and future progress in computer hardware and software technology should lead to command and control systems for AAW which are operationally practical. Recently attempts have been made to use similar, highly automated, command and control systems in ASW, such as the ASWSCCS which is now actually in use on several ships. We are convinced that the degree to which a command and control system can be feasibly automated depends almost exclusively upon the quality of the input data. In particular, we feel that the root of all problems in the ASW/CIC is the low quality and the low acquisition rate of the input data (in spite of many advances in sensory technology). In essence, therefore, the system must extract for its output accurate and timely information from a relatively meager input. The problems involved in this task are sufficiently complex that a completely, or even very highly, automated system would require sophisticated and expensive computer hardware and software beyond the existing capability.

One of our original goals was the development of a mathematical model of the ASW/CIC that would define an adaptive control system in which changes of the priority state, keyed to the threat environment, would be automated. (See section 3 for a discussion of these states.) Two of the basic assumptions of this program turned out to be false. First, the priority system which determines the information flow within CIC is not a simple threat-environment system; it is in fact a complex system which involves several interrelated priority structures (see section 3 for details). The second assumption that our investigation failed to confirm was that the ASW/CIC operation was already understood from a systems point of view, so that existing models would provide a basis for our study. In fact, we found no evidence, at the levels of classification available to us, to indicate that the ASW/CIC has ever been approached as a total system, or even that the requirements of the system have been adequately defined. The CIC seems to have evolved on an empirical basis out of practical considerations, such as physical constraints, rather than through a form-follows-function systems design approach.

With the considerations of the preceding paragraph in mind, we made the decision to change the course of our investigation and construct the very basic conceptual model of the ASW/CIC required before we could address the problem of an adaptive system. We have developed such a model, and it is described in the next section. We have not rejected the idea of an adaptive control system, and this idea may be worthy of further study; we did feel, however, that we would be unable to make a meaningful approach to the problem without first developing a theoretical substructure for the analysis.

Our model, potentially, can pave the way for immediate, significant, cost-effective improvements in the Navy's ASW capability. While we agree that ships with computerized command and control systems will probably ultimately develop high operational efficiency, because of the cost and time involved in research, development and production such ships will not be available in sufficient numbers to constitute the Navy's primary ASW destroyer force for a number of years. The cost of back-fitting existing ships with large computers appears to be prohibitive. We believe that there is a good possibility that our model could be used as the first step in the development of an inexpensive, but operationally more effective, CIC. Through this model we have achieved a deeper understanding of the real operation of the ASW/CIC. In fact, we have reached to such a degree of understanding that it should be possible now to determine functions that could be automated, using inexpensive and available hardware, to produce a system which would be operationally effective at greatly reduced manning levels. This point will be discussed further in the recommendations of section 4.

3. Description of the model

A. The action phases. Our point of departure is the assumption that a destroyer is, at any given time, in exactly one of a known set of modes, or phases, of ASW operations. We have chosen this particular beginning because these phases are identified in established doctrine and are easily recognized by the personnel involved. (We note that our assumption here does not imply that we have ignored the reality of multiple threats and multiple missions, for we recognize that this investigation could have been pre-destined to failure by a simplistic approach in which this reality was ignored or solutions to this very complex problem were pre-concluded. We feel that an analysis of multiple threats/missions is possible within the framework we have developed; this is also discussed further in section 4.)

With a little thought, one can see that it is reasonable to expect that the particular set of phases used to describe the operation of a destroyer as a complete system may be inappropriate to describe coincidentally the operation of all of its subsystems; we feel that this is indeed the case with the subsystem we have identified, very loosely, as "CIC". Specifically, for the CIC we have distinguished a set of six action phases, based on our recognition that a distinct communications pattern exists in each. We identify these action phases as follows:

1) search;
2) detect/alert;
3) evaluate threat;
4) prosecute;
5) attack;
6) post-evaluate.

In order to clarify the meaning of these terms, we trace the scenario of a possible action. Initially, the ship is steaming in a search phase. At the first indication of a possible contact, other detector operators are alerted, and we pass to phase 2. During the second phase the decision that a contact actually exists is made, and the CIC is brought to a higher readiness state. As soon as the contact has been verified, we pass to phase 3; here the nature and the magnitude of the threat posed by the contact are established, and a recommendation is made to command on the action to be taken. By the end of the evaluate-threat phase, the following decisions will have been made by command: to act, the method of attack, the attack center (ASAC, Sonar, UB, Conn, or Weapons Control[1]). The end of phase 3 occurs as soon as all three of these decisions have been made.

During the prosecute phase, effective control passes to the specified attack center which, subject to command override, directs maneuvers and commits a particular weapons system to the attack. At the instant the weapon is irreversibly committed, the attack phase begins. In the actual time from irreversible commitment of the weapon (usually weapon launch) to weapon exhaustion (including a "hit"), contingency plans are implemented and weapons systems are prepared for a follow-on attack. The attack phase terminates, hopefully, with some indication of success in the attack. The results of the attack are then evaluated during the post-evaluate phase, and the decision made to return to the prosecute phase for the same target, or to search, evaluate, or prosecute for a new target. A flow diagram to illustrate this example scenario is given in Figure 1.

B. The fundamental network. The next step is to describe the general communications structure in the CIC, which will enable us subsequently to describe the information flow in each of the six action phases. As indicated in section 2, transmission of CIC information in non-NTDS equipped destroyer types is effected through a highly complex array of

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1. Weapons Control is an "attack center" only for a surface action. Otherwise its function is to release the physical interlock (in NTDS as non-NTDS) which assigns the ASROC weapons system in UB.

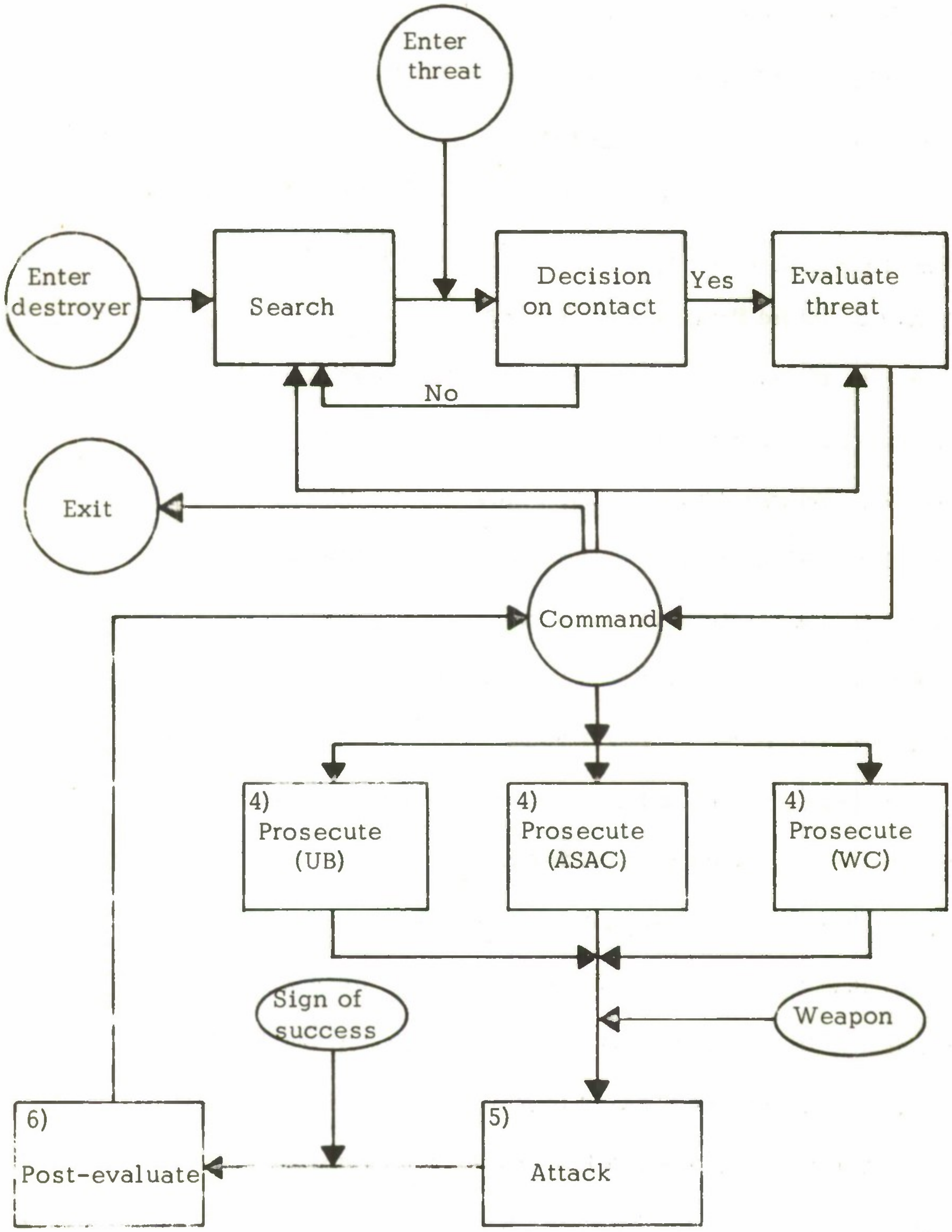

Figure 1. Example Scenario.

of nodes and branches as the fundamental network.

Within this framework it is possible to analyze the communications problem at several levels. At the most basic level, we ascertain which nodes must be connected by branches in each specific action situation. At the next level, the links in each branch are assigned priorities; this priority structure functions as follows: if a high priority link is unavailable, the communicator will attempt to send his message via a less desirable, i.e., lower priority, link. At still another level, with all channels operating, the evaluator must assign priorities that determine the order in which he accepts information from the various channels. We believe that a careful analysis of the interplay between these three distinct priority structures, and the ways they influence the fundamental network, is essential in order to understand how the CIC really functions. We shall return to this question after we complete the description of the physical communications framework.

A generalized node-branch network for a "CIC" in its ASW configuration is shown in Figure 2. The nodes of this finite graph correspond to existing stations aboard representative ships. (Some of the stations shown are not located within the physical confines of the CIC, so that we are not actually showing the CIC per se. However, the nodes that we do include are all essential for an analysis of the CIC information flow.) Although some of the branches have been excluded for simplification, it is the opinion of our panel of CIC-qualified officers that the branches included here are those which are actually utilized in normal operational communication equipment. In the communications system of any ship, many of the channels are redundant (some purposely so), and information routings are, in practice, often a matter of personal taste. Because of this complexity and this variability, the system actually realized in exercises, as well as combat situations, effectively defies analysis. Described below is a conceptualization of the system which is sufficiently simplified that systematic analysis becomes practical, but which is sufficiently flexible to contain all the necessary elements of a real-world combat communications system.

It seems appropriate, and it has been the most productive for us, to visualize this communication system as a network. This network accepts raw input data from the outside world, processes it, and conveys specific output information and commands to various stations. The network consists of nodes, i.e. manned stations, and a set of branches, which connect some of the nodes. On a specific ship, under specific action conditions the branch can be activated by more than one link. In this context, a link may be a dial telephone, a sound-powered telephone, a human messenger, a face-to-face conference, a pneumatic tube, an electro-mechanical servo system, or any of several other communications devices by which information is normally transmitted into, out of, or within CIC. To communicate along a branch, first a link is chosen, and then if communication by that link is possible, a channel is open. If the first link is inoperable or in use, an attempt is then made to establish the channel via an alternate link (in the same branch). We refer to the system situations. Even this simplified network contains redundant branches; for example, information can be transmitted from sonar to the evaluator via either the sonar supervisor or plot 1. While redundancy is not necessarily undesirable, in an environment where space and manpower are at a premium, redundant portions of the network are immediately questionable.

The portion of the network shown by dashed lines is the part which is necessary for a surface action. The analysis of this portion is not difficult, but we have not included it in this report for the sake of brevity. However, this portion of the fundamental network must be taken into account in any new CIC system design.

C. The phase nets. The node-branch network shown in Figure 2 is sufficiently general to describe the distance communications patterns for the six action phases described above. Each of the phases requires that a specific, well defined, portion of the fundamental network be in a primarily active state while the remainder of the network remains primarily passive. We shall refer to these sub-networks as phase nets. Each action phase requires a unique net except for the prosecution phase, in which two basic phase nets exist because in different situations the prosecution may be handled by UB or the ASAC. The complete set of phase nets, with the active portion of the fundamental network shown by the heavy lines, are given in Figures 3 through 9.

The phase nets in the figures below give an immediate pictorial indication of the level of complexity of the communications problem in each phase. The diagrams of the fundamental network and the phase nets

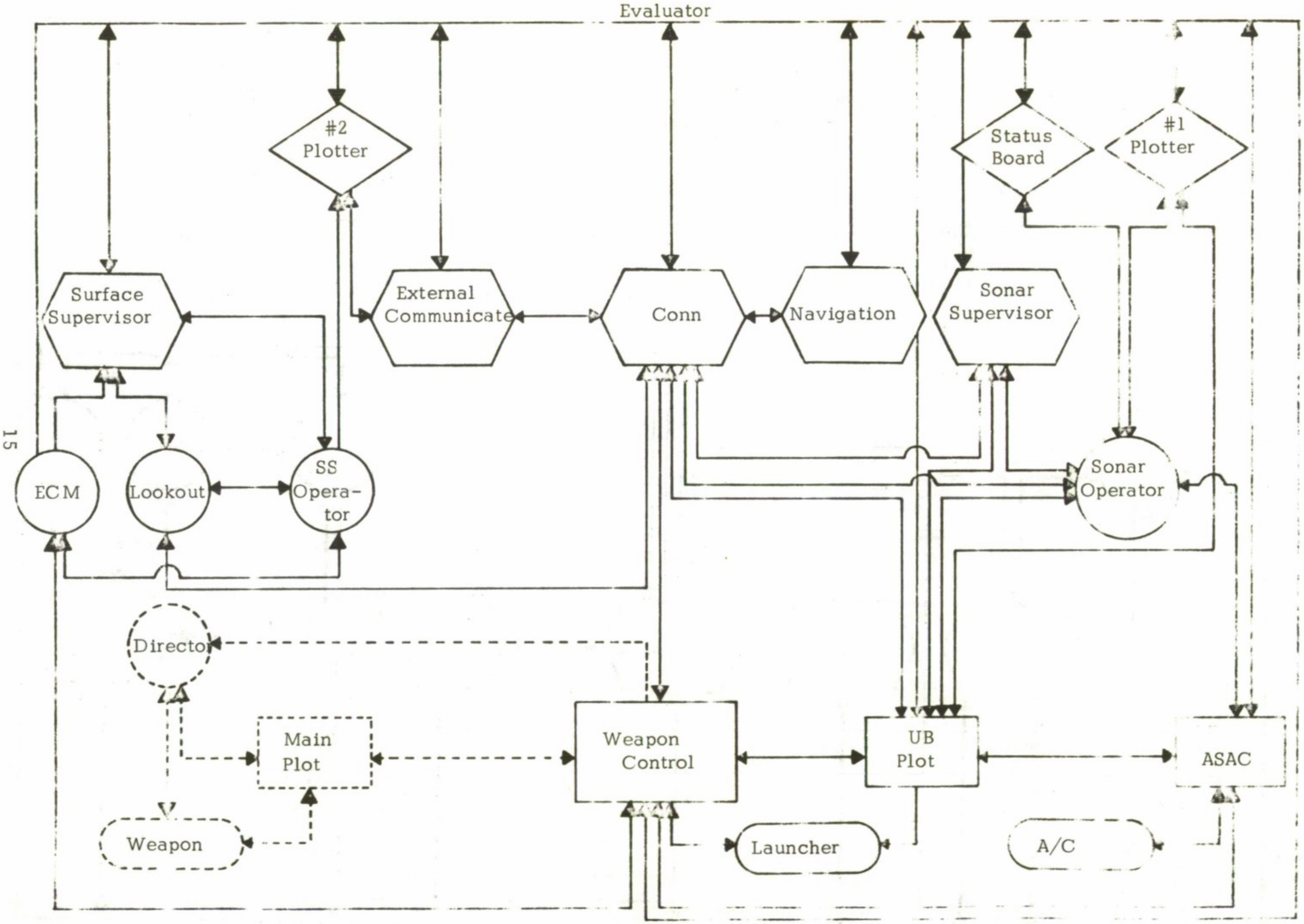

Figure 2. The Fundamental Network

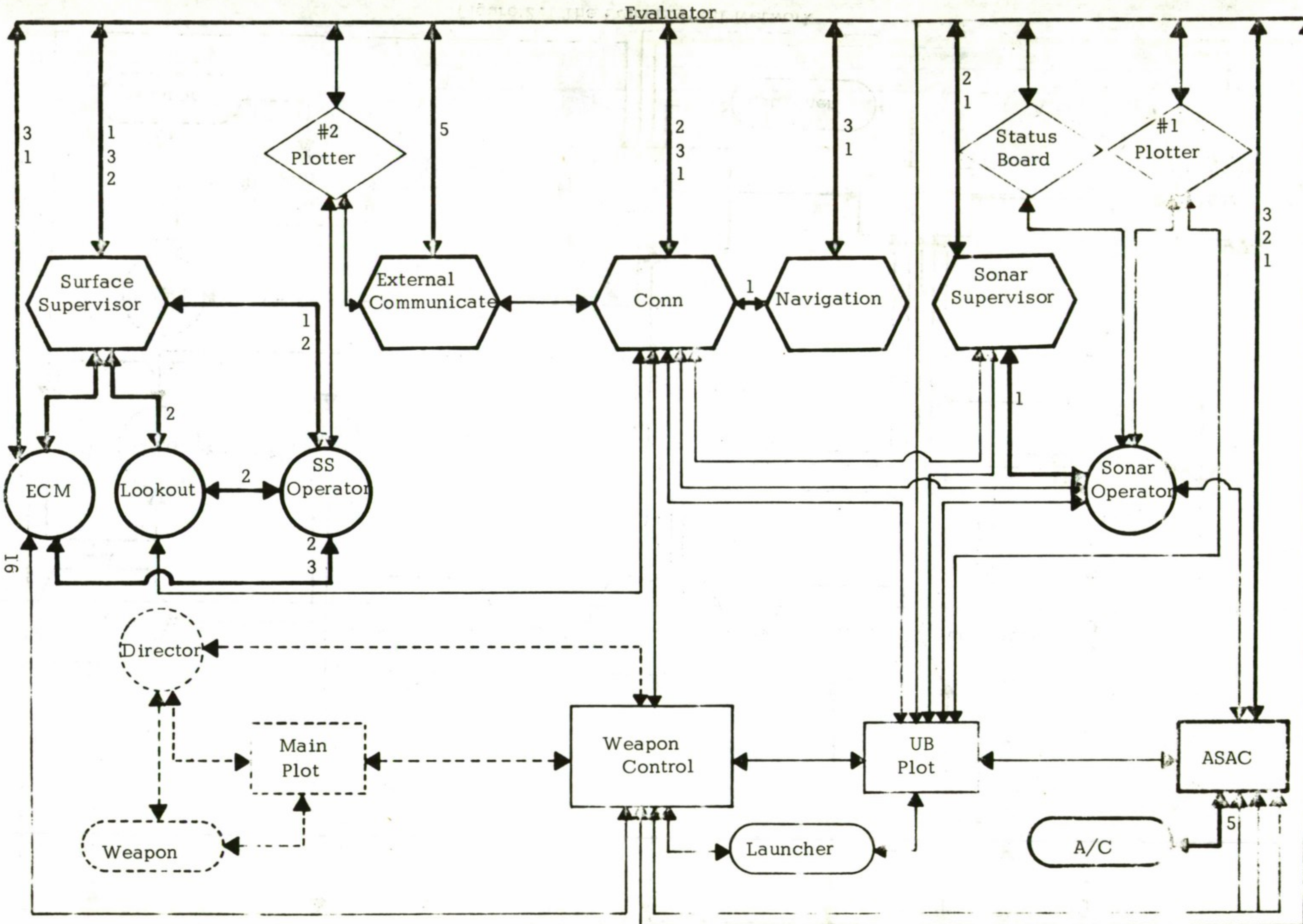

Figure 3. Phase net 1. (Search)

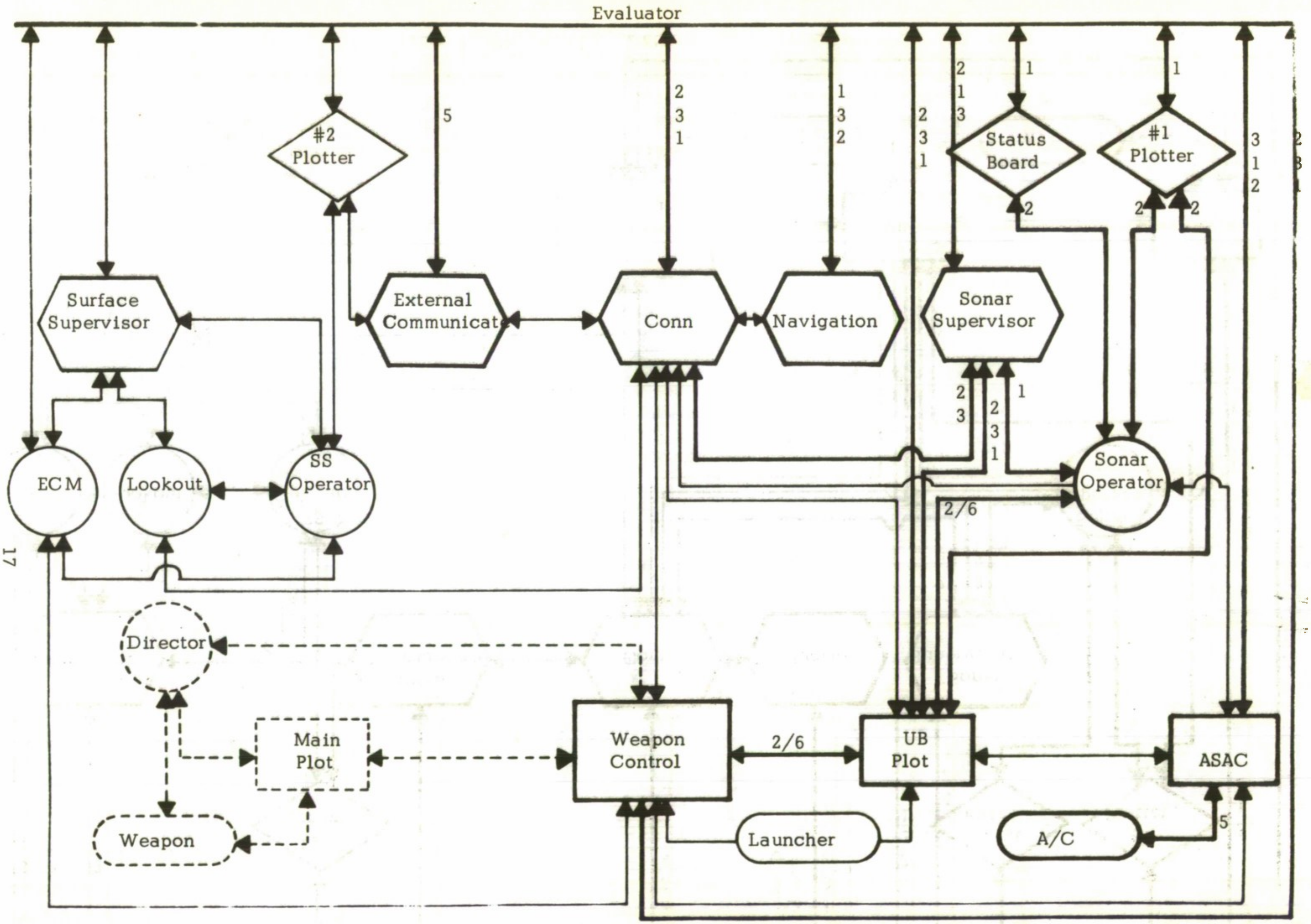

Figure 5. Phase net 3 (Evaluate)

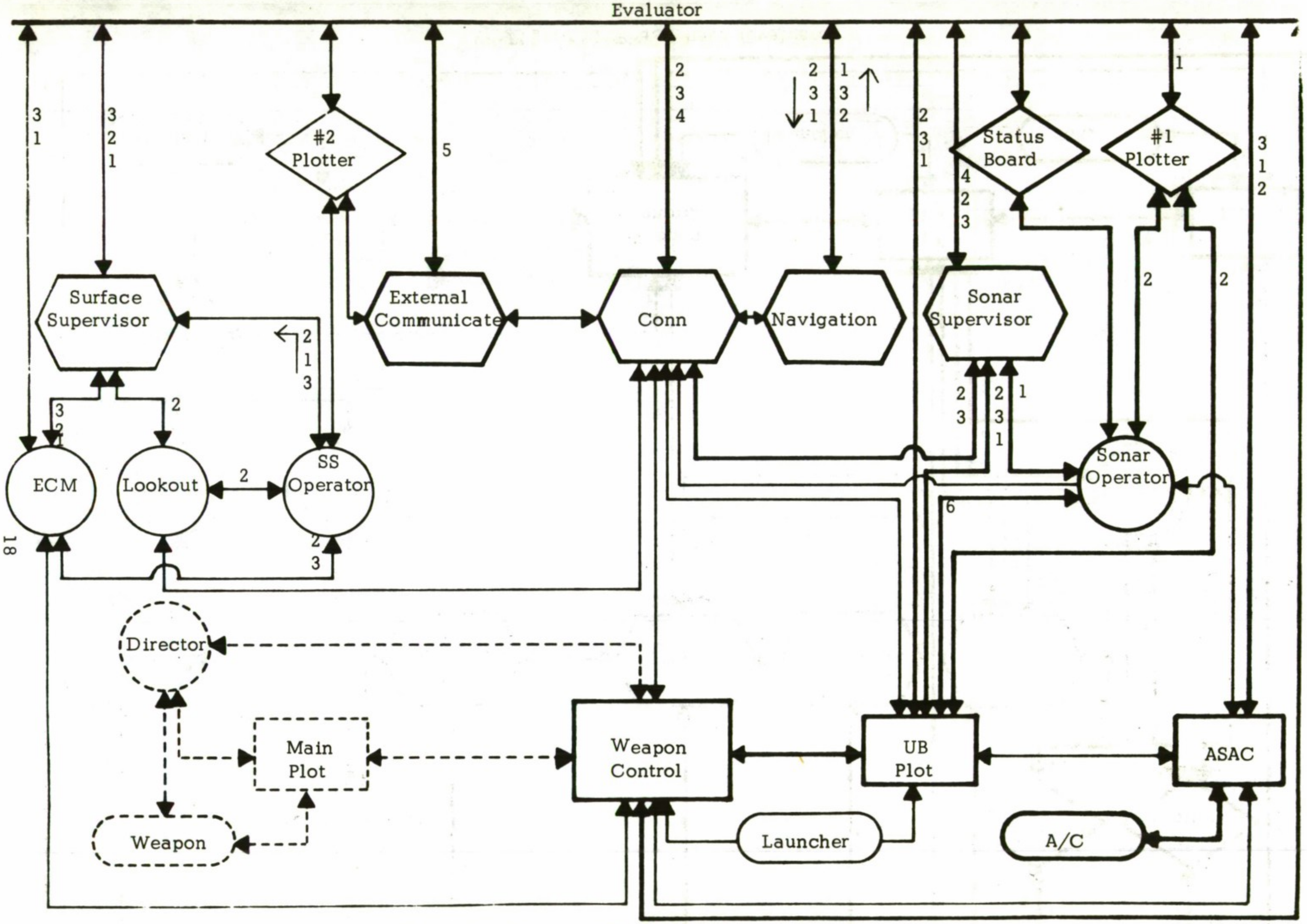

Figure 4. Phase net 2 (Detect)

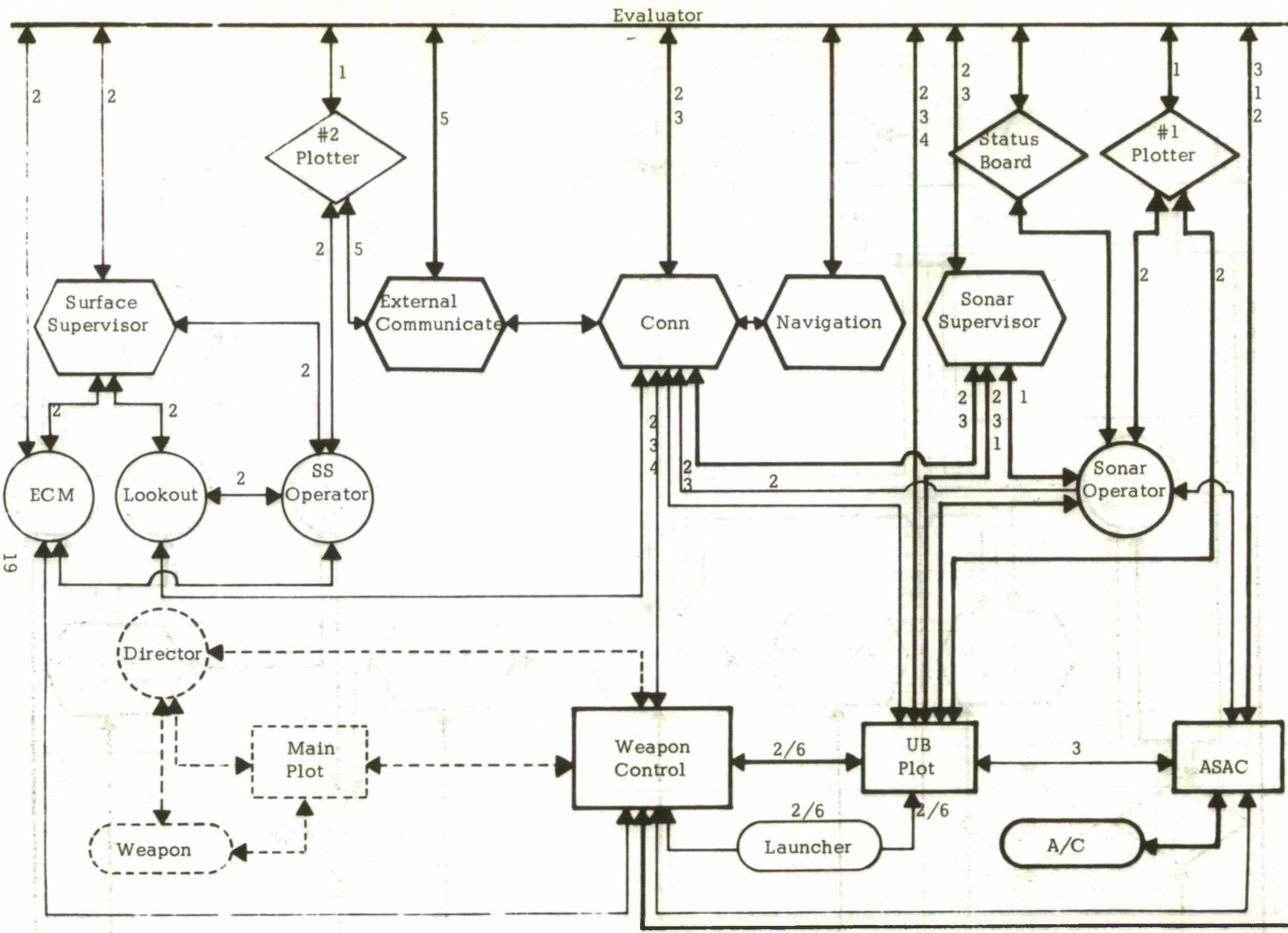

Figure 6. Phase net 4a (UB Prosecute).

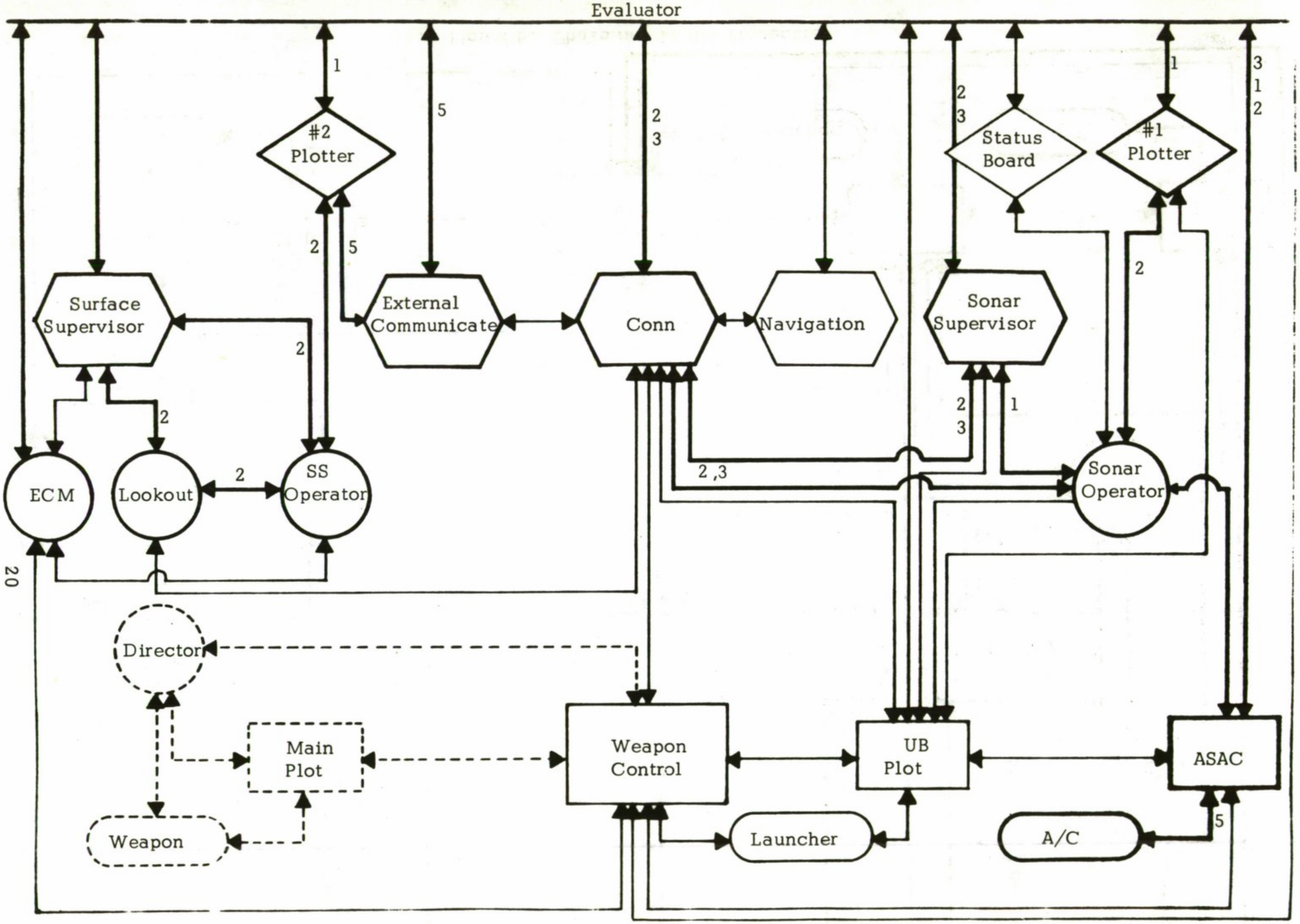

Figure 7. Phase net 4b (ASAC prosecute).

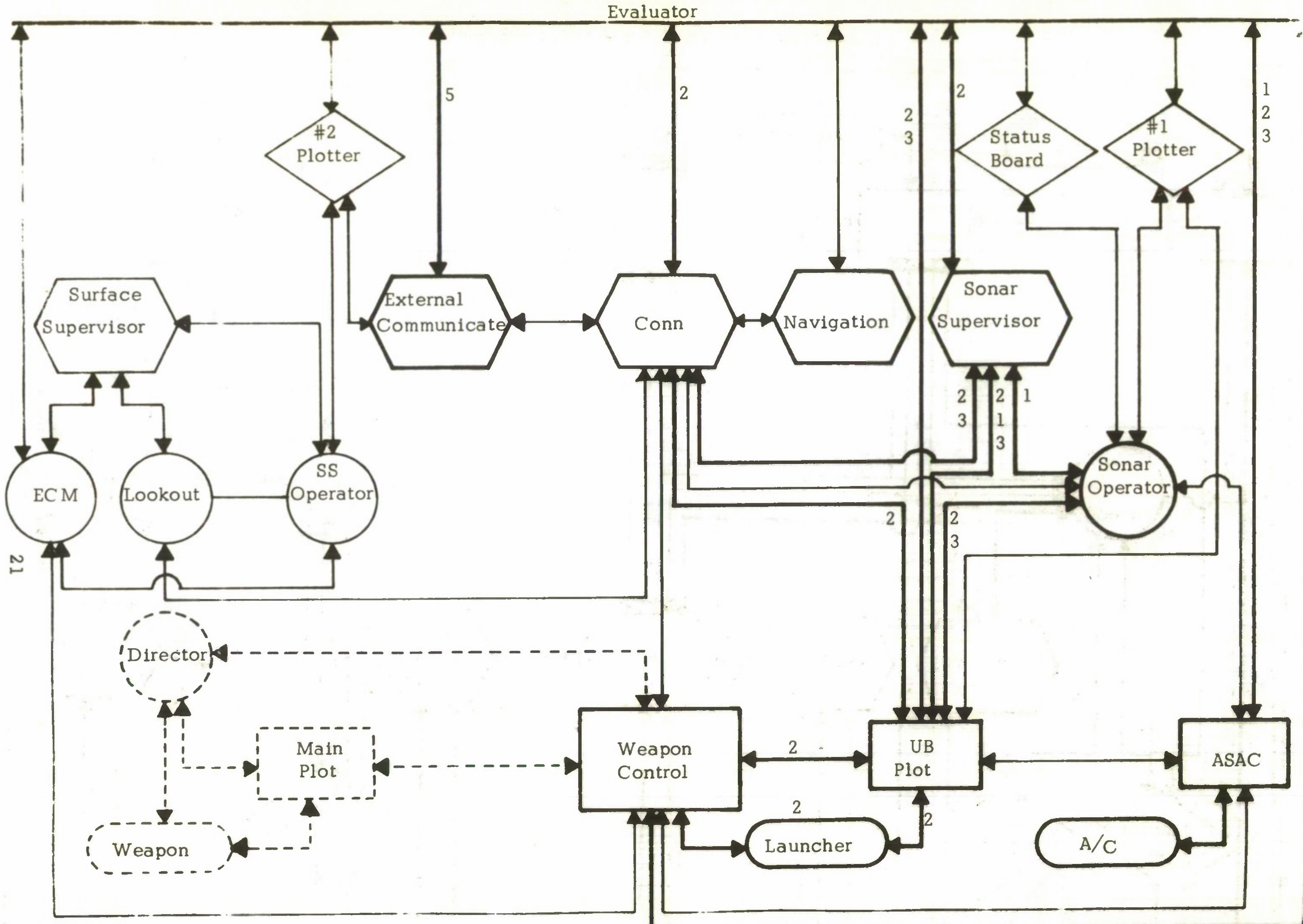

Figure 8. Phase net 5. (Attack)

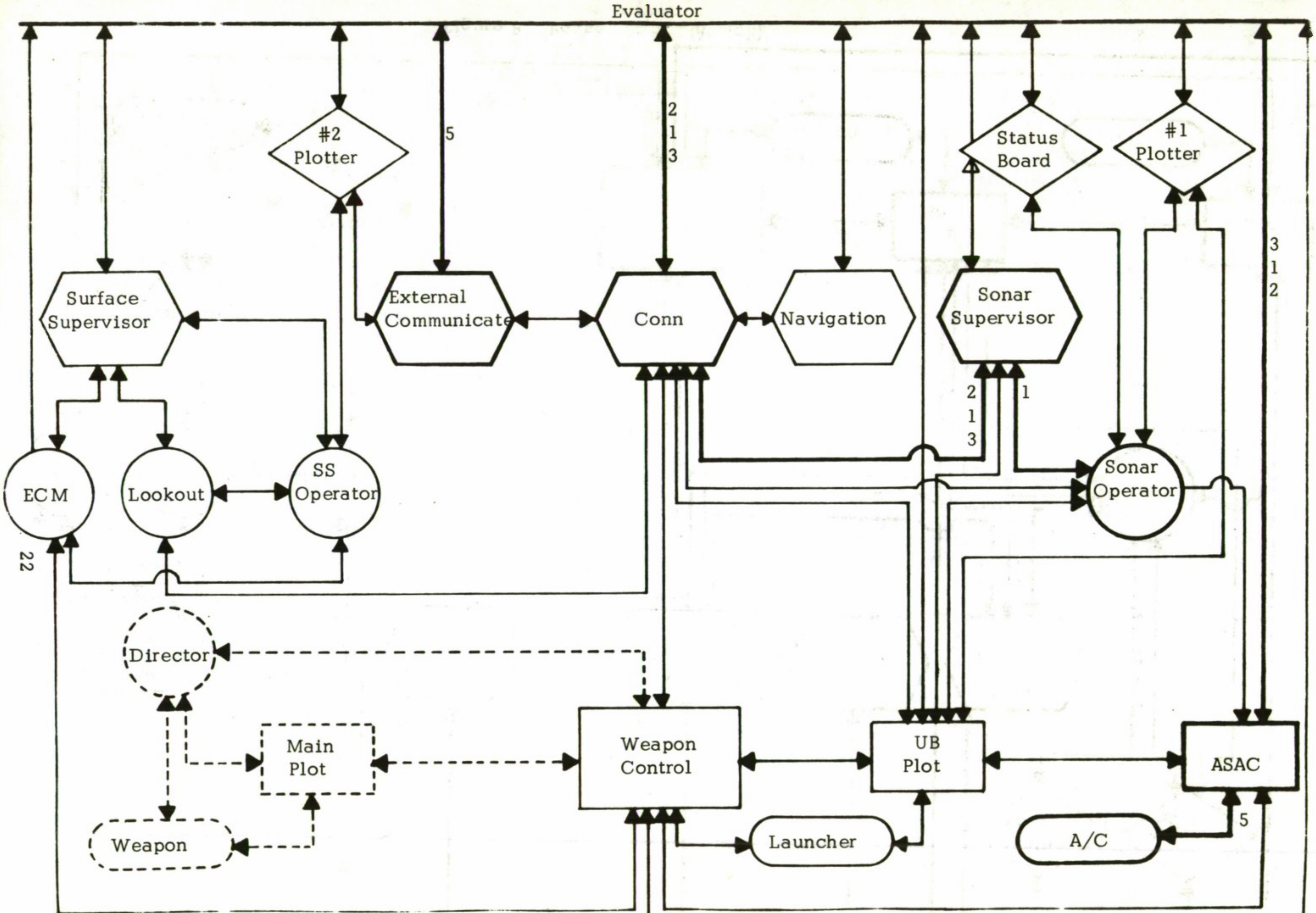

Figure 9. Phase net 6 (Post-evaluate).

have been constructed on the assumption that at least one assist unit is present, so external communications at the evaluator level have been included. External communications at the command level have been omitted.

D. Clusters. The phase net diagrams given in Figures 3-9 show clearly the binary branches, i.e., those which connect two nodes. However, these binary connections alone are insufficient to describe the actual communications framework because in practice there are often three or more nodes which are connected simultaneously. For example, the 1JS sound-powered telephone circuit may connect any or all of the nodes, Conn, Sonar Supervisor, UB, and Evaluator, together. These higher-order connections will be called clusters. (We avoided the apparently obvious terminology choice, "loop", because it fails to convey the simultaneity of the multiple connections.)

The clusters that are realized in practice normally vary to some extent from ship to ship, but there is apparently sufficient commonality of practice to provide for a general description. It is important to describe the clusters here for at least two reasons. First, these clusters constitute an intrinsic characteristic of the phase nets, so that without them the description of the information flow would be incomplete. In addition, these clusters are essential in the analysis of how the evaluator interacts with the remainder of the system. This latter point will be considered along with the question of priorities after the description of the physical communications framework has been completed.

Diagrams are also helpful in visualizing clusters. In Figures 10 through 16 we have drawn graphical representations of the clusters in each of the action phase nets. We emphasize that our purpose is only to describe clusters that are widely used in the ASW/CIC. There is, as noted earlier, considerable variation in practice, so that our work should be understood as an attempt to approximate the general situation, rather than as an attempt to be precise.

In Figures 10-16 the branches are indicated by two distinct types of lines. A solid line indicates that the channel is normally open, whereas a dashed line indicates that the channel is not actually in use most of the time, but that there is important information transmitted sufficiently often to consider the branch operational in the given phase.

E. The links. We have now established the basic CIC communications structure, i.e., we have shown where information normally flows in each of the action phases. Our next step is to indicate how the transmission of information is physically accomplished, and this will then complete our description of the physical communications framework.

We begin with a list of the types of communications links normally used in the CIC. These are:

1. direct (face-to-face);
2. sound-powered phone;
3. intercom;
4. announcing system;

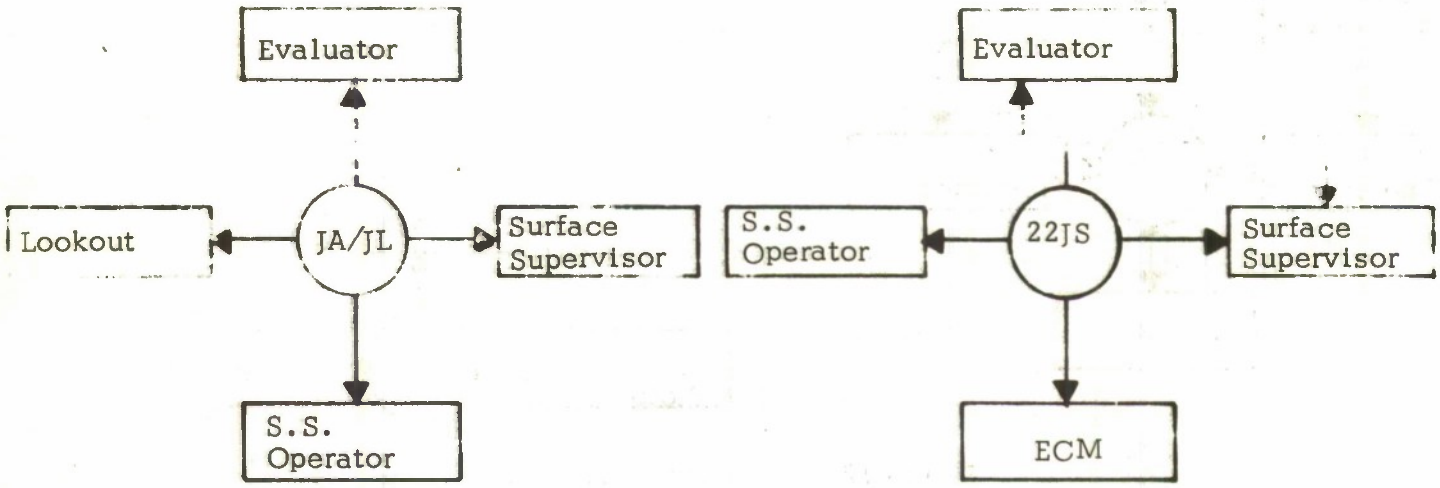

Figure 10. Clusters in Phase 1.

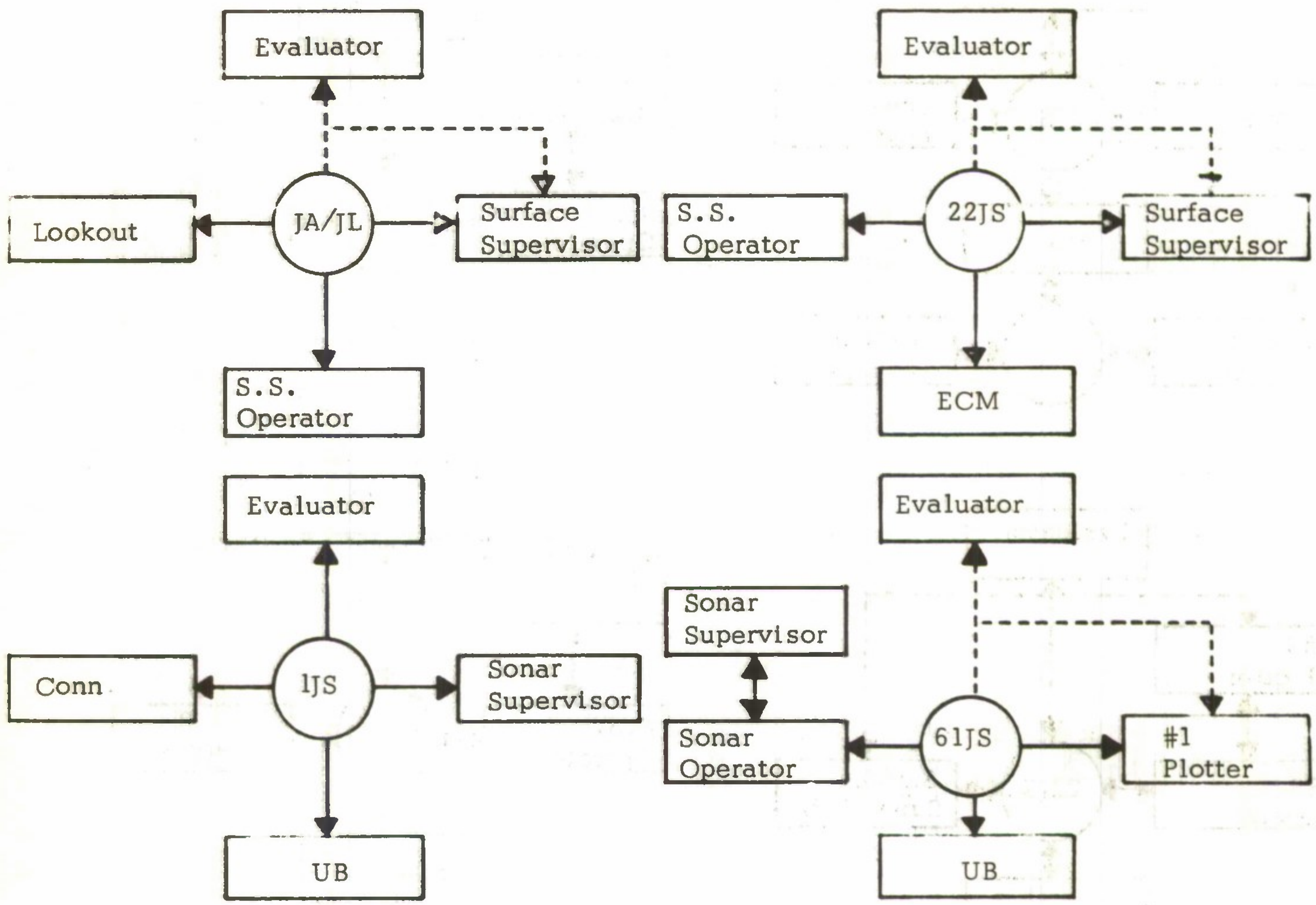

Figure 11. Clusters in Phase 2.

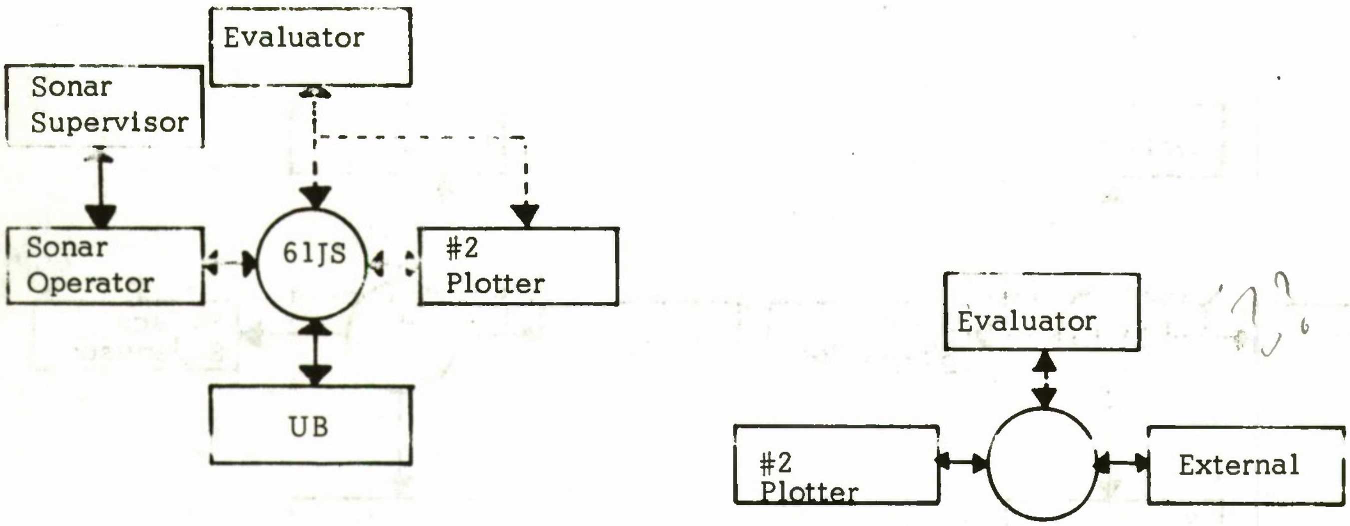

Figure 12. The Cluster in Phase 3.

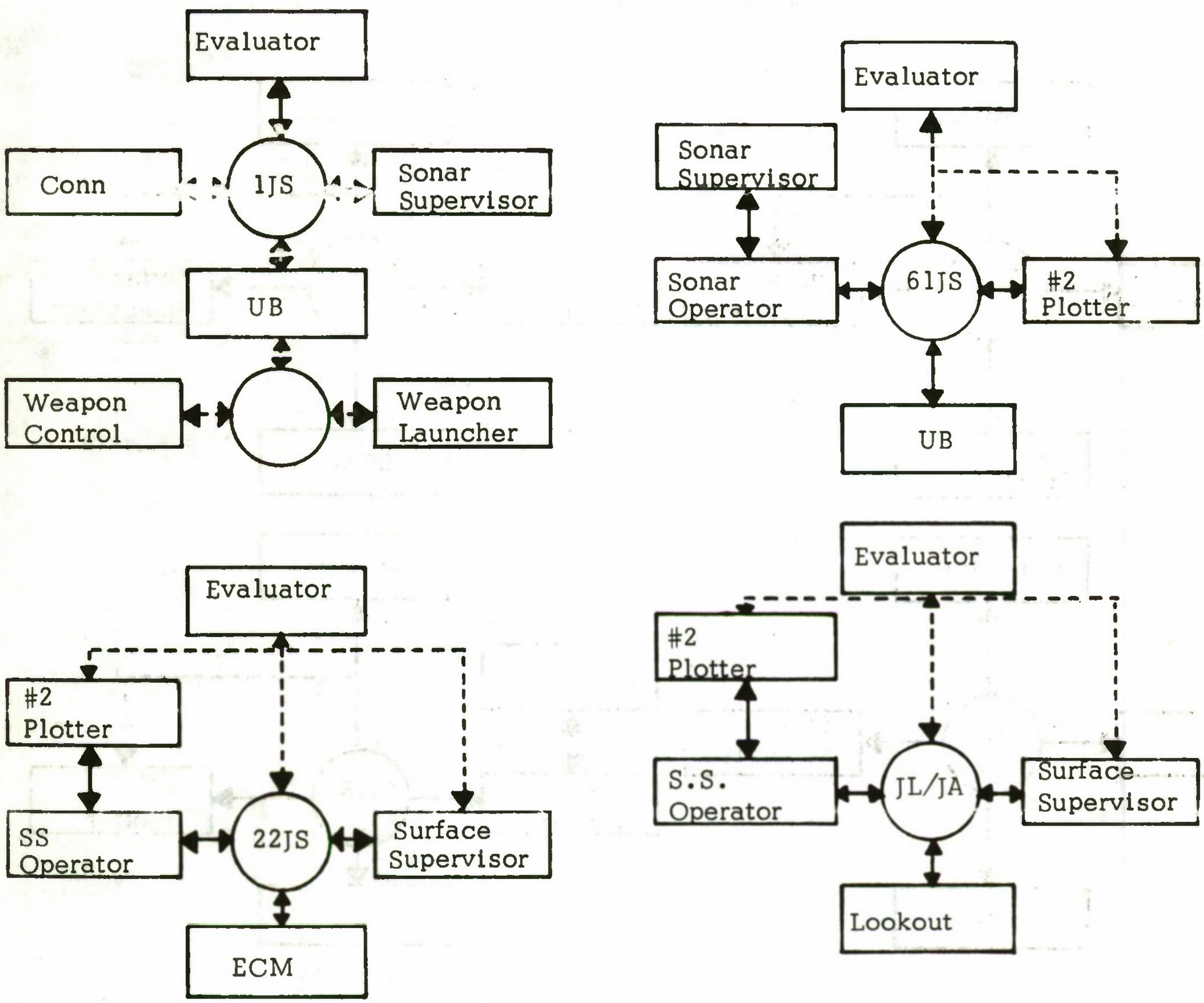

Figure 13. Clusters in Phase 4a.

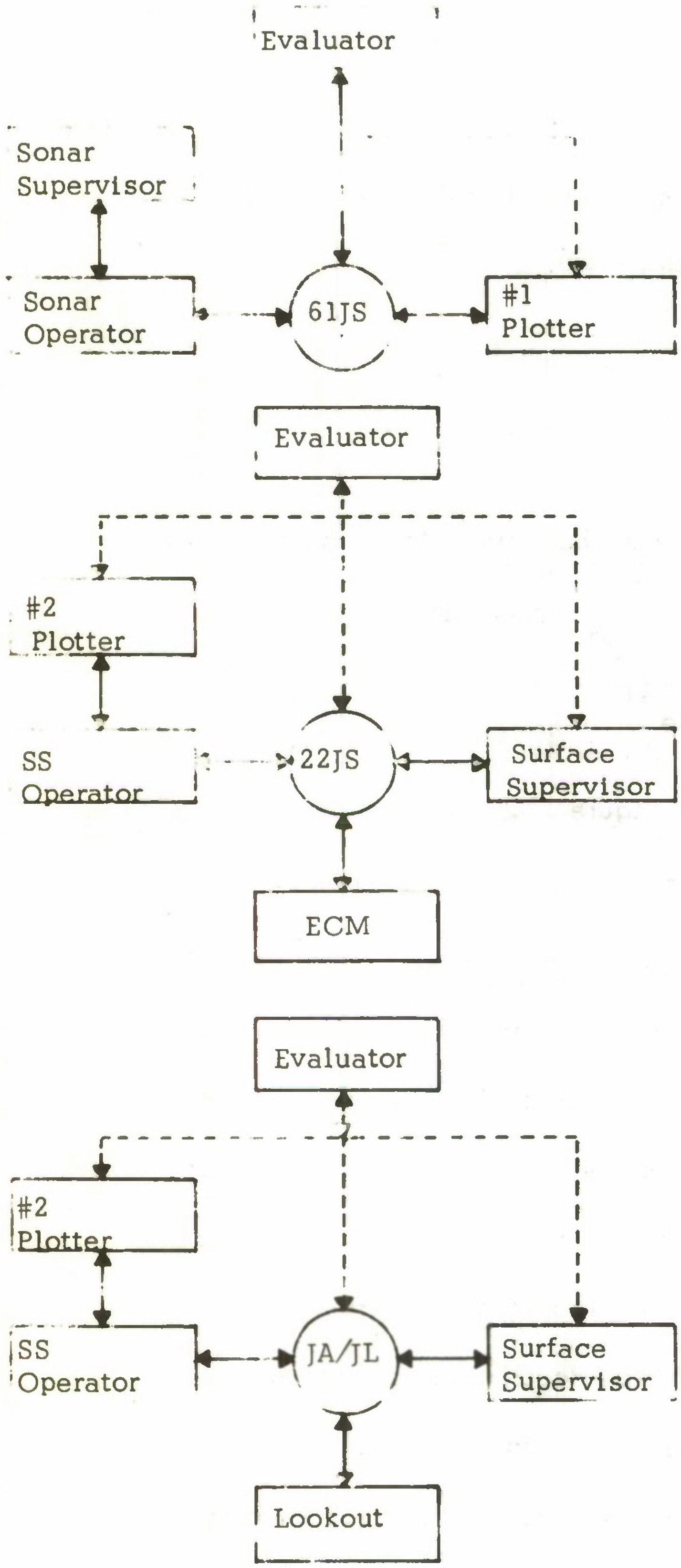

Figure 14. Clusters in Phase 4b.

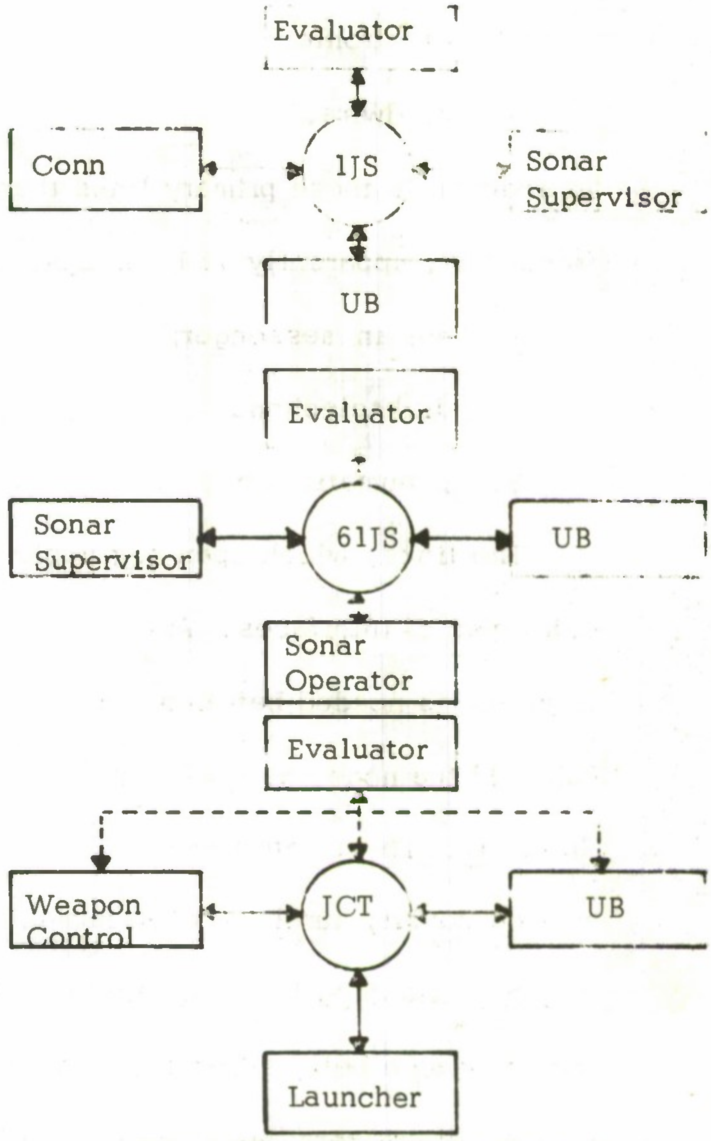

Figure 15. Clusters in Phase 5

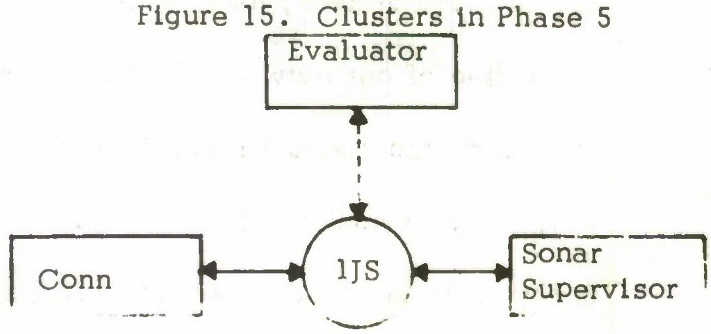

Figure 16. Clusters in Phase 6.

5. electronic;

6. hardwire.

In addition to these primary links there are several that are used less frequently, apparently as back-ups. These are:

7. human messenger;

8. dial telephone;

9. pneumatic tube.

The links, which open communications channels, also require various types of interfaces. An interface is needed between the link and the node, as shown in Figure 17. These interfaces may be visual, aural, or even human. For example, a visual interface may be a flashing light, an analog display, or a printout. An aural interface may be a bell, a buzzer, or a loudspeaker. We also include humans, for example talkers, as interfaces rather than as nodes, partly to prevent cluttering of our network diagrams, and partly because the functions performed by the nodes have a different intrinsic nature than does the basic function of a human interface. We have not included a detailed interface analysis in our study, but we feel that an in-depth study of the interface problem will be essential in any CIC system design program.

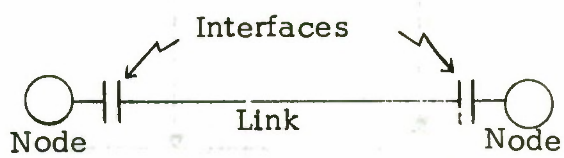

Figure 17. An open channel.

In general, information may be transmitted along a given branch by any of several links. The choice of the link used to activate a channel is usually governed by a rather definite priority system which, of course, has some variation with ships and personnel. The link priorities, which we discuss further in section 3F, depend upon the action phase. We have made an attempt to determine general usage of links, and the description of our findings is contained in the phase net diagrams, Figures 3-9. The numbers shown beside the various active channels correspond to the numbers assigned to the links in our list above. The order of the numbers is significant in that the priorities are listed in descending order, i.e., the link listed first has highest priority, etc. A slash between two numbers indicates that both links are used simultaneously.

F. The priority system. In any communications network every message has a priority, i.e., a claim upon the services of the physical facilities and the human beings which comprise the system. For example, in our national telephone system service is on a simple first-come, first-served basis. In this example, all messages are assumed to have the same value, so they all receive the same priority. In the CIC, however, messages have different values, so the CIC operation requires a more complex priority system. We shall attempt here to indicate how various elements interact to influence CIC message priorities.

The ultimate priority assigned to a particular message depends upon human evaluation of a set of sub-priorities. We have identified three priority hierarchies which determine this evaluation process. Each hierarchy consists of a more or less complete set of relative value rankings, where a message's rank within each hierarachy is determined by a set of value criteria characteristic of the hierarchy. Individual message priorities are not actually assigned via this complicated logical structure, but the structure enables us to identify the sources of message value. In a practical situation, the whole process is done automatically, and almost sub-consciously, by the human beings at the nodes of the network. Each operator would say that his assignments are made on the basis of the ship's doctrine and his own past experience. The system succeeds if his rankings agree with those which the evaluator would have assigned under the same circumstances, and it fails to a greater or lesser extent if they do not.

The first, and best defined, hierarchy of priorities is completely determined by the operational phase of the ship. This hierararchy is completely general, and essentially independent of the communications configuration on a particular ship. These are truly exogenous priorities, because they are determined by the external environment of the system. Apparently they can be uniquely determined, preassigned, and manipulated by equipment in the CIC.

In each operational phase the evaluator requires information from a well defined set of nodes. This need, when specified in terms of nodes and branches, actually defines the phase net for each phase. Therefore, the phase nets are really a form of priority assignment for messages from various nodes under specified conditions. Nodes which generate low value messages in a specific external environment are excluded from that phase net; i.e., their messages are given very low, or even zero, priority. These externally determined message values will be called the <u>phase priorities</u>.

We emphasize that this first set of priorities is externally imposed and does not depend upon human value judgments. These message priorities are <u>unique</u> and, while they vary sharply with changes in the action phase, they can be easily assigned. In fact, our panel of CIC-qualified officers had no difficulty in assigning phase priorities to various types of messages. Since this hierarchy is apparently well understood, we shall not elaborate on it further.

If the system in actual practice were to consist simply of nodes and branches, then the phase priorities could be assigned mechanically within each operational phase. The design of an appropriate message processing system would then become a problem for a communications engineer. However, in reality the network contains people at the nodes, and links which activate the branches. In order to pass from a branch in the model world to a channel in the real world, someone must choose a link. This choice is made according to a set of values which we shall call the <u>link priorities</u>.

Link priorities depend largely upon the following two major factors: the communications equipment available for service as links, and the human characteristics of the individuals who man the nodes which are connected by the links. Thus, these priorities must be specified according to the demands of a particular CIC.

We believe, further, that it is impossible to achieve the invariance which is characteristic of the phase priorities. While it may be possible theoretically to obtain a standardization of hardware on board a ship, the maintainability and the effects of human feelings would still need to be considered. For example, in some given situations, two distinct individuals may choose different links to effect a branch, and the problem is compounded by the additional consideration of utilization. Doctrine helps here, but it is unable to cover all contingencies, and it is also unable to specify the "best" link for all people. Therefore, the link priorities are humanized, or personalized, and they do not lend themselves to quantification, or mechanization. It follows that any concrete realization of the CIC model must make provision for human characteristics in the link priorities.

The third set of priorities is engendered exclusively by the physiological and the psychological characteristics of the evaluator. This hierarchy of priorities arises because although it appears to be physically possible to deliver all available information to the evaluator's station, if this complete delivery is encouraged, the evaluator becomes so inundated with data that he has no time to assimilate or evaluate the information which he is receiving. Optimization of information flow, therefore, does not optimize unit effectiveness, and it may very well downgrade the performance of the complete system. In successful CIC operations, the evaluator consciously, or sub-consciously, limits the amount of information which he receives. The message values which govern the way in which the evaluator accepts information are called the <u>load priorities</u>.

The load priorities define the balance between the evaluator's desire for complete knowledge and his ability to assimilate information. They depend to some extent upon his confidence in the individuals who are manning the CIC, but they probably depend even more upon his own personal characteristics. For example, the aggressive, decisive evaluator requires less information from the phase net than does the cautious, conservative individual who rechecks each datum with the originator. The times required for a particular evaluator to comprehend and assimilate information, and to formulate recommendations, are very important here, as is his propensity toward aural or visual presentation. Thus, load priorities are humanized, as are the link priorities, and provision must also be made for human characteristics in the determination of load priorities.

This completes the description of our basic model. There remains a substantial amount of work which must be done in order to use the model to obtain the practical results mentioned in section 2, and we shall elaborate on the problems involved here, as well as some related problems, in the next section. In addition, the model we have described here serves as the basis for some specific action recommendations which we shall also present in the next section.

4. Immediate Consequences and Long Range Implications

A. Evaluator. While many of the details of this model have not been developed completely (we shall have recommendations for further development in the section 4B), even from its present preliminary form certain useful results become apparent. The first finding is particularly relevant to the evaluator.

In the course of our investigation, two rather well defined approaches to the load priority problem have emerged. We shall refer to these approaches as the modes of operation of the CIC. One group of evaluators uses a method which is best described as a sampling technique. When this method is used, the evaluator follows trends in the development of the problem by sampling, say, every third or fourth message from the repetitive sources. In this mode of operation the evaluator does not impede the flow of information on the one hand, but neither does he attempt to assimilate every message from each channel. He follows the development of the status estimate, rather than focusing his attention on the exact current status.

The second approach to the load priority problem uses single nodes, or combinations of nodes, as "sub-evaluation" stations. In this mode of operation information is to some extent evaluated at these stations, and it then collects there. The "processed" information is then supplied to the evaluator on a demand basis, i.e., when he asks for it. This mode requires that the evaluator have a high order of confidence in his sub-evaluators, which can come only as a result of relatively long association and careful training.

We believe that the sampling mode is most useful when the nodes, and therefore the data which they supply, are of questionable reliability. In this mode the distortions introduced by faulty message transmission or reception tend to be smoothed out. On the other hand the sub-evaluation, demand, mode appears to be the superior of the two when it is practical, and it also seems to hold more promise as a means of extending the capability of the CIC. That is, if certain functions of the CIC are automated in a man/machine system, then a computer actually serves as a sub-evaluator which provides information to human evaluators on demand. When the human specifies the operational phase, the computer can evaluate the phase priorities of its inputs, but the evaluator determines the information required, and the rate and the form of presentation.

Recommendation for immediate action. We recommend that the evaluator's training provide him with an introduction to this model of the CIC and the message priority structure which it defines, so that he may view the CIC as a single system which should be designed to respond efficiently to his direction. The evaluator's training should also introduce him to the concept we have called "modes of operation", and outlined above.

The evaluator should understand that the alternative mode in which he exercises positive control over the way in which information is presented to him is a mode in which he may often be forced to choose between messages which are presented to him simultaneously. These choices involve a waste of time, especially for the less experienced evaluator, to the extent that the evaluator may fall behind in his evaluation of the problem. Such a mode should never be recommended or encouraged in any way, because it lacks the flexibility to respond effectively to a series of crisis situations. The two preferred modes, demand and sampling, minimize slippage of the evaluation, and thereby increase the efficiency of the CIC. Where it is practical, sub-evaluation with preplanned override of the demand control system can be particularly responsive to rapidly changing situations.

We recommend further that the evaluator's training program make him keenly aware of the importance of human factors in the CIC organization. He must realize fully the impact that human characteristics of members of his team have upon this system. (In fact, some such understanding is crucial if he is to grasp the significance of the "mode-of-operation" concept and be able to apply these ideas successfully.) An understanding of how the human characteristics of his crew influence the CIC operation is one key to the evaluator's ability to optimize effectiveness of the system.

Of equal importance are the human characteristics of the evaluator himself. He should know his own capabilities and limitations, and be able to make rational adjustments in the system to accommodate them. In order to facilitate the development of this ability, the evaluator should have an objective, accurate and, where possible, quantitative appraisal of his own traits.

Recommendation for future action. Although our team is not competent to make professional judgments in human factors situations, a committee of experts in this area should consider the problem, and perhaps recommend the development of a battery of tests that will measure, for a student evaluator, such elements as his time rates in comprehending, assimilating, and correlating information. Such characteristics as his ability to plan, organize, control, and communicate could also be tested. His speed in drawing conclusions, i.e., making decisions, on the basis of processed data is also important. These are only examples, and a careful analysis should be conducted to produce a comprehensive list of those personal traits of the evaluator which effect the CIC operation. The student evaluator could be tested, informed fully of the results, and brought to understand how he can use this knowledge to operate a better CIC.

B. The Model. As mentioned earlier in this report, we believe that our model potentially can serve as the basis for improvements in the Navy's ASW capability. We would like to mention two possible contributions.

(1) Multiple Threat Environment. An immediate first approximation to the communications problems in a multiple threat environment can be made by combining, i.e., overlaying, of phase net diagrams. The potential sources of trouble must occur where a single channel must simultaneously carry information for both phases. These channels, and therefore, the overloaded nodes, are those where the active channels of the two phase nets coincide. Because of time limitations, we were unable to continue the development of the model in this direction.

Recommendation for immediate action. The phase nets for multiple threat environments should be constructed, the problem areas identified and studies undertaken to determine whether it is possible to process the data in some other way. This action is possible without further development of the model itself.

(2) Communications. In its present form, the model is not sufficiently developed to make an immediate impact upon communications problems, but we have identified from the model the directions in which it must be developed to make contributions in this area. Implementation of the studies suggested here will provide the quantitative information necessary before the model can be applied to specific problems. For example, a detailed analysis of the functions performed by the evaluator appears to be appropriate for the next step. Flow charts which show various decisions (for action recommendations to command) the evaluator must make during ASW operations should be constructed. In Figure 18 we present an example of the type of flow chart that would be useful in an analysis of the evaluator's functions. This example is rather general in nature, and detailed charts are needed to describe typical specific action scenarios.

When the study of the evaluator's functions has been completed, a reasonable choice for the next step seems to be a detailed analysis of the functions performed at the various nodes. It should be possible to relate these functions to the needs of the evaluator. This analysis, in order to be successful, must contain a solution of the priority problem, i.e., a complete understanding of the interrelationship between the priority structures identified in section 3, so that ultimately a unique, phase-dependent priority system evolves. When this deep understanding of all crucial aspects of information flow is achieved, it should then be possible to decide which functions can be profitably automated, and how best to design a system as outlined in section 2.

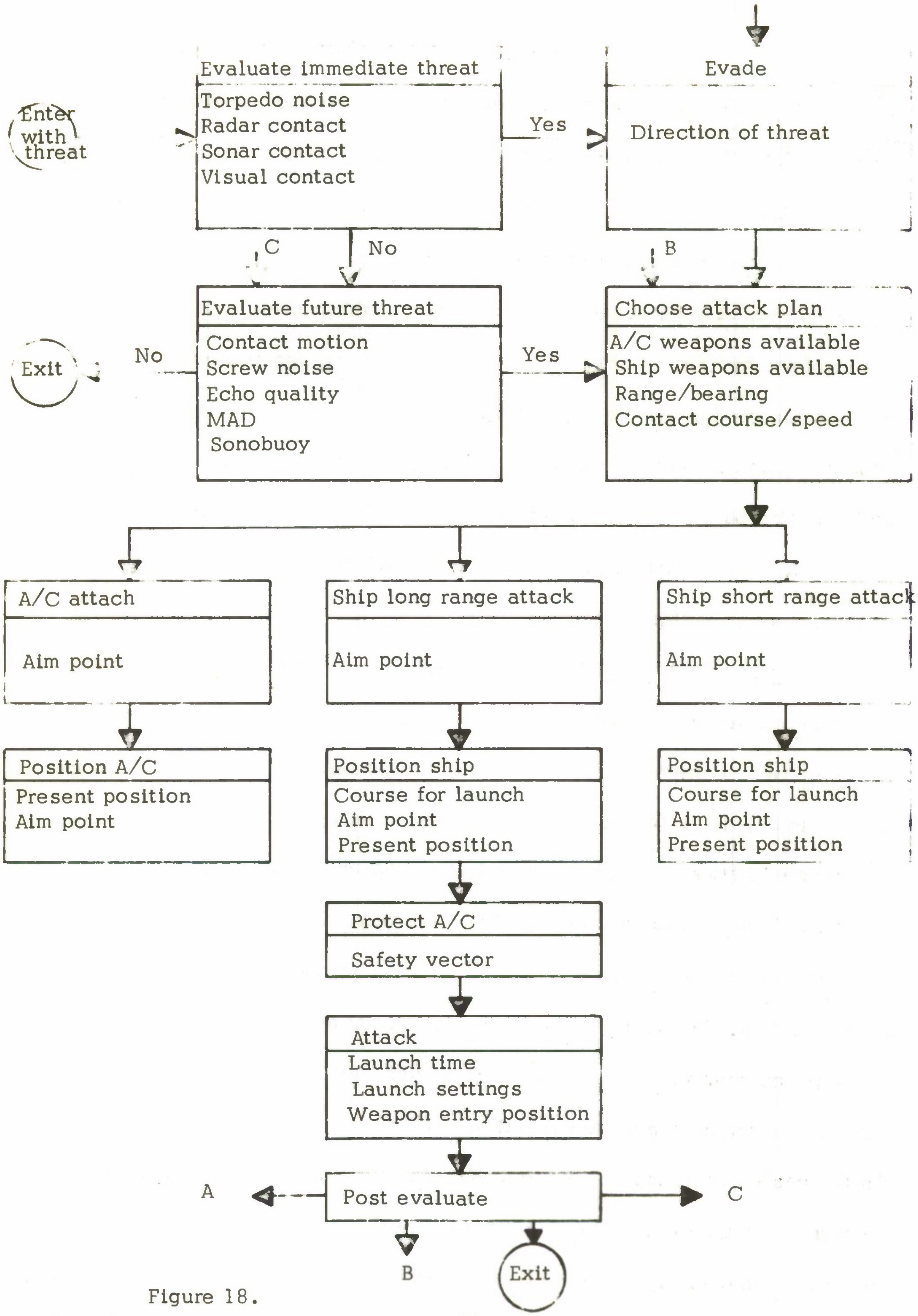
Enter with threat
Evaluate immediate threat
Torpedo noise
Radar contact
Sonar contact
Visual contact
Yes
Evade
Direction of threat
C
No
B
Evaluate future threat
Contact motion
Screw noise
Echo quality
MAD
Sonobuoy
No
Exit
Yes
Choose attack plan
A/C weapons available
Ship weapons available
Range/bearing
Contact course/speed
A/C attach
Aim point
Ship long range attack
Aim point
Ship short range attack
Aim point
Position A/C
Present position
Aim point
Position ship
Course for launch
Aim point
Present position
Position ship
Course for launch
Aim point
Present position
Protect A/C
Safety vector
Attack
Launch time
Launch settings
Weapon entry position
A
Post evaluate
C
B
Exit

Figure 18.

When our model has been supplemented with the additional information just described, there will arise the question of feasibility of computer simulation of the enlarged model. While it seems impossible to account for the variability in the actions of the humans at some of the nodes, it may still be possible to obtain useful information from a partial model of the system. It may be possible to conduct a probabilistic study wherein random threats are generated, the nodes constitute the states in a Markov chain, and data are put into the system and processed on a probabilistic basis. On the other hand, it may be better to study the system as a game, with human players. We believe that this decision cannot be made at this time.

C. Commonality of AAW and ASW ships. Our group appreciates that the armament and the sensors differ significantly between ships configured for these two functions. This investigation was initiated to facilitate the automation of the ASW CIC, but there remains the larger question of the relationship between CIC operations in the ASW and AAW modes. From a command and control point of view it is evident that much of the display hardware and computational capability requirement could be met with a single system. The fundamental question of command and control problems of single purpose vs. multi-purpose destroyers appears because the interfacing requirements are essentially different in the two situations. On the basis of this model, we feel that it should be possible to design a common computation/display unit which interfaces directly with the sensors when operating in an AAW environment, and which interfaces with humans at sonar, ECM, and similar sensors used in ASW operations. The more fundamental problem of the capability of the platform to sustain armament to accomplish both missions remains, but a computer which serves as a common bookkeeper/displayer seems possible. This computer would interface with clusters in the same way that the evaluator now obtains his data. Overloads of the system occur because the evaluator is unable to assimilate all of the material displayed, not because the compute/display unit is unable to handle the data input.

Recommendation for immediate action. Investigate the hardware requirements for a console by which a human, the sonar officer for example, could place the conclusions based on his evaluation of the sonar situation into a visual display where it would be held for the evaluators consideration.

D. Administrative considerations. Our model of the CIC information system assumes that all channels are open at all times. Unfortunately, a channel can be blocked by administrative as well as technical failures. This possibility cannot be ignored, because the normal shipboard administrative structure is not the same as the CIC command structure. If the sensor nodes do not respond to directives from the evaluator, the system also fails. This type of failure can easily be blamed upon the CIC communication problem, when in fact it occurred for completely different reasons.

E. Command and Control. Finally, we wish to point out what appears to us to be a major, and very delicate, problem area, namely the bridge-CIC complex. We hasten to add that we do not claim to be originators here -- the problem already has been the object of several studies and the subject of several articles in recent literature (see, for example, [2]). Our comments are added because the problem arose repeatedly during our investigation, it has not been solved, and it effects the potential value of our work.

We agree with long established tradition that the ship's commanding officer should make the tactical decisions, because his very selection for that position carries the implication that among the ship's officers he has the best qualifications, in terms of experience and total ability, for making decisions. It follows that the commander should have available the very best picture of the tactical situation possible. However, in practice he is often faced with the following dilemma. If he remains on the bridge during ASW operations, then his tactical information comes "second-hand", and he risks a situation in which the evaluator is better informed on the tactical problem than he himself, possibly even to the extent that it would be better for the evaluator to make the command decisions. If, on the other hand, the commanding officer stations himself within the CIC, or sonar control, he risks the possibilities of losing the perspective from the bridge, of duplicating the efforts of the evaluator, and of impeding the normal flow of information he wishes to receive.

We believe that the CIC, albeit a system per se, must be regarded as a subsystem of the ship itself. As such, its purpose is to provide the commanding officer with the information he needs to make decisions. Recent advances in display technology offer some hope that a solution of this problem may be within reach without major design changes. On the other hand, solution of the problem may require a whole new physical layout of the bridge-CIC complex, as suggested in [2]. At any rate, the mechanics of how the CIC's responsibility to the commanding officer can be best discharged should be the subject of a systematic and thorough investigation.

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13. ABSTRACT

This paper is devoted to a detailed analysis of the information flow in the CIC of non-NTDS equipped destroyer types. Our analysis is accomplished via a model of the CIC operation which is keyed to the threat environment. The model has two fundamental components. One is the physical communications framework; the other is a message priority structure, which we found to consist of three distinct hierarchies, two in addition to the one which is determined by the threat. Recommendations for action to improve CIC performance, which are based on the analysis, are included.

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